Efficiency effect of changing investment structure on China's power industry

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ABSTRACT

Based on data of China's power industry from 2005 to 2010, this research applies the SBM approach of the dynamic DEA model (one of the efficiency measurement methods that corresponds with economy–energy–environment trinity) to analyze the Energy-Efficiency-Dynamic Total Factor Productivity (ECDTFP[1]) of the power industry and the efficiency effect of changing investment structure on the industry. The results indicate that the introduction of foreign capital and the reform to lower the share of state investment are conducive to raise the ECDTFP in the power sector. In addition, it is important to focus on vital factors such as the production structure, the industry concentration and the regional technology investment intensity, which significantly affect the productivity of the power sector in future policies and reforms.

Contents

1. Introduction

In 2002, Chinese government launched the system reform of the power industry following the principles, "separation of plant and network, segregation the main business from the minors, separation of transmission and distribution and electricity bidding".

By far, the reform has failed, to some extent (Lin [1]). The stagnation of this reform is mainly attributed to the drawbacks of the pricing and market access mechanism. In 2010, state-owned and state-holding enterprises contributed most of the total industrial output value of China's power industry (see Fig. 1)
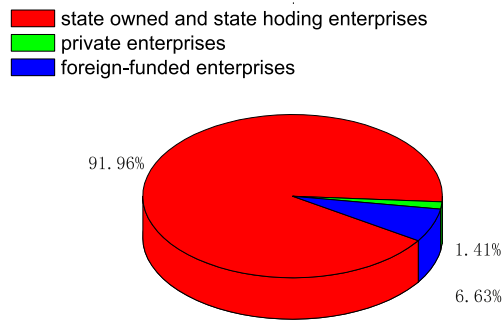
Fig. 1. The composition of industry output value in China's power industry in 2010. *Source*: China Statistical Yearbook 2011.
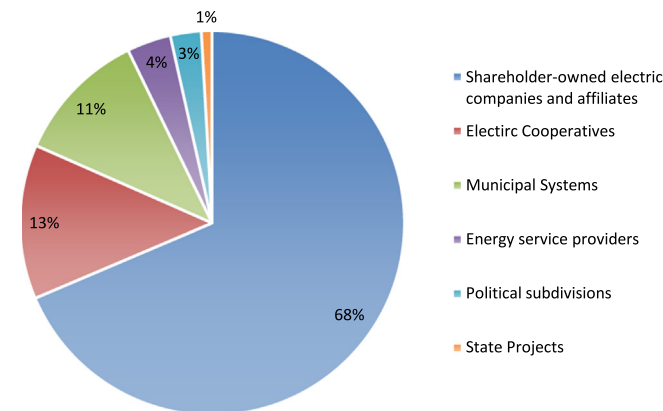

Fig. 2. Generation portfolio in American's power industry 2010. *Note*: Federal utilites serve < 0.1% of customers. Sum of components may not add to 100% due to independent rounding.
Source: Edison Electric Institute, Business Information Group, based on 2010 preliminary data from the U.S. Energy Information Administration.

Compared with China, the phenomenon of state-owned monopoly in other countries is not as serious as it seems. For example, in terms of the 2010 American generation structure, electricity supplied by shareholder-owned electric companies accounts for nearly 69% in total, while state projects account for only 1%. Besides, the state-owned power enterprises mainly served for the public utilities (see Fig. 2).

At present, the introduction of block electricity tariff and mechanism of coal-electricity price linkage proves that the reform of pricing mechanism was taken seriously by the government who will vigorously make relevant policies to support the reform. On the contrary, the effort to deal with the market access mechanism is relevantly less. There is no practicable policy to break the state monopoly and loosen the restriction on market access in the power sector. Due to the difficulties in quantifying the impact on power industry development of investment structure optimization, the momentum for bringing foreign and private investments is still insufficient. What will the impact of the investment structure on the power industry be? Based on this research question, we quantify the impact of investment structure reform in China's power industry by applying the Tobit model based on the ECDTFP drawn from the dynamic DEA model in this paper.

Since China's reform and opening-up, economic growth has largely depended on investment in natural resource. Economic development has caused natural resources depletion and environmental pollution in China. Many researches have been conducted to study energy efficiency and the impacting factors of China. The influence mechanisms between state capital and energy efficiency are as follows.

Firstly, from the aspect of natural resource properties in China, initial distributions of resources is controlled by the government. On the premise of incomplete governmental supervisory mechanism,

state-owned enterprises which have closer relationships with government will have cost advantages over other enterprises. Such resource allocation mechanism does not comply with the market economy and will lead to resources under-allocation. Moreover, the extra benefits gained from the political connection would restrain the development of the company itself (Yang [2]). Misallocation of resources mainly resulted from the low productivity of state-owned companies (Nie [3]).

Secondly, from the aspect of the own properties of state-owned companies, the main features of the companies include high policy-related pressure and ambiguous property rights.

Compared with private and foreign companies, it is easier for state-owned companies to get financial support and resources. With looser budget constraint and ineffective incentive system, state-owned companies are considered to be operational inefficient. All the state-owned enterprises have been affected by government intervention to some extent and obtained protection as well as subsidies under the country's policy, such as price control of energy and raw materials. The direct consequence of subsidies on companies is to lower the initiatives to raise efficiency (He [4]).

Based on the above analysis, the research hypothesis is put forward: breaking the state monopoly; and reforming the investment structure would raise efficiency in the power industry.

The main contributions of this paper are as follows:

Based on the fact that there is high centralized state capital in the power industry, we conducted an empirical study on the relationship between investment structure reform and industry efficiency. The study will offer a theoretically basis for the reform of the power industry.

On the definition of energy efficiency of the electric power sector, the Energy-Efficiency-Dynamic Total Factor Productivity (ECDTFP) is adapted as the efficiency indicator. This indicator which was proposed by Lei [5], will reflect the basic requirements of sustainable development and the internal relation among economic–energy–environment.

This paper is organized as follows: Section 2 is the literature review of efficiency measurement and investment structure study. Section 3 contains two parts. Section 3.1 shows the introduction of the model we adopted while Section 3.2 gives the data analysis. In Section 4, empirical research and analysis are presented. Section 5 is the measurement of the impact of reform investment structure on the total factor efficiency of power industry. The last section is the summary and policy suggestion.

2. Literature review

Färe et al. [6] introduced Data Envelopment Analysis (DEA) into the research of efficiency and productivity. In contrast with Stochastic Frontier Analysis (SFA), there is no need for DEA to start with hypotheses for parameters and production functions. The calculated results turn out to have good robustness. DEA model has been widely used in the renewable-energy field in recent years (Halkos et al. [7]; Lee et al. [8]; Azadeh et al. [9]). Song et al. [10] summarized the environmental efficiency evaluation based on data envelopment analysis. In the research projects of efficiency, this method has been greatly used. Chitkara [11], Park [12] and Olatubi and Dismukes [13] adopted DEA model to evaluate the efficiency of electric sector and coal-fired power plants. Lam and Shiu [14], Xie [15] evaluated the operation efficiency of the thermal power sector with panel data in China by adopting DEA model.

In order to obtain the efficiency of the power sector under the carbon emission constraint, it is necessary to introduce the carbon emission factors into the model.

Environment cost–benefit curve and Kuznets curve are two widely applied methods for investigating environment pollution. Kuosmanen et al. [16]adopted environment cost–benefit analysis to discuss the economic impact resulted from the environment policies like emission reduction. Gong and Shen [17] pointed out the existence of Kuznets curve for both national and regional levels as well as the provincial heterogeneity of pollution emissions.

By summarizing the existing researches, there are two main approaches to introduce the environment factors into the model. The first approach is to take it as the undesirable outputs directly and include the reciprocal or negative form of the undesirable outputs into the production model. This approach is adopted in researches such as Färe et al. [18], Scheel [19],Wang et al. [20]. The second approach is to regard it as the input elements (Hailu and Veeman [21]; Chen [22]).

The principle "the less, the better" can be reflected by seeing the reciprocal or negative form of pollution as input factor. However, pollutions and inputs cannot increase or decrease at the same proportion by this mean, which is not consistent with the real production process (Hailu and Veeman [21]). At the same time, the two methods dealing with pollution do not take the slack of input and output into account (Li [23]). Thus, it indicates the Directional Distance Function will overestimate the efficiency when there exists slack of input and output.

To overcome that, Tone [24] introduced Slack-based Measure (SBM) model to deal with undesirable outputs. In previous studies, environmental factors have not been given enough attention. This will bias the estimates of efficiency and total factor productivity. In recent years, DEA-SBM model demonstrates a new approach to deal with the environment undesirable outputs (Emrouznejad et al. [25]). Qu et al. [26] adopted SBM model to evaluate the efficiency of thermal power industry in China.

The single period efficiency evaluation could lead to over-excitation in the short-term and under-excitation in the long term (Jiang [27]). Including dynamic effects into productivity study is a new development in sustainable development research. Tone and Tsutsui [28] developed dynamic DEA model within the slacks-based measure framework which was proposed by Färe and Grosskopf [29], and according to the characteristics of carry-overs, they classified the carry-overs into four categories: desirable, undesirable, free and fixed. Tone and Tsutsui [28] applied dynamic-SBM (DSBM) model to estimate the efficiency change over time in the power-generation division of 50 electric utilities consisting of 41 U.S. and 9 Japanese companies. Lei [5]developed the DSBM model from the Malmquist productivity index to study total factor productivity. It can better control the non-proportional changes in inputs and at the same time fit the uncertainty of the market external factors in using the non-oriented dynamic-SBM model to deal with the undesirable outputs.
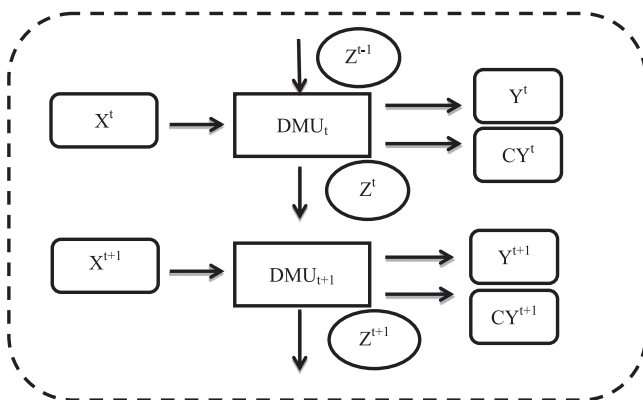

Fig. 3. Principle of the DSBM model.

3. Methodology and data

3.1. D-SBM model

The dynamic-SBM (DSBM) model is adopted in this paper. Traditional SBM model focuses on optimization in a single period separating the input–output effect in adjacent periods (Tone and Tsutsui [29]) and cannot reflect the idea of sustainable development. In this model, energy–environment–economy factors will be taken into consideration (Lei [5]). This research further contribute to the efficiency study of the power sector in China.

Dynamic factors and carbon emission factors would influence the estimation of efficiency. Thus, this model will evaluate sustainable efficiency from the two prospects. The entire estimation process is based on a non-oriented SBM model, allowing various elements to change non-proportionally at the same period. The principle of this model is shown as follows (see Fig. 3).

Assume that there are $t=1, 2,…, T$ periods and $j=1, 2…, n$ decision-making units (DMU). Each decision making unit (DMU) contains X input elements and Y output elements. The CY denotes carbon emission elements; Z denotes dynamic elements (take output in t period as the input elements in $t+1$ period).

The objective function of DSBM model with carbon emission constraint is defined as Eq. (1):

$$\rho^* = \min \frac{1-(1/(m+r))(\sum_{i=1}^{m} s_{it}^-/x_{iot} + \sum_{i=1}^{r} s_{ilt}^-/(z_{iot}-1))}{1+(1/(s+p+r))(\sum_{i=1}^{s} s_{idt}^+/y_{idot} + \sum_{i=1}^{p} s_{iut}^-/y_{iuot} + \sum_{i=1}^{r} s_{ilt}^+/z_{iot})}$$

s.t.

$$x_{iot} = \sum_{j=1}^{n} x_{ijt}\lambda_{jt} + s_{it}^- \quad i=1,…,m \quad t=1,…,T$$

$$z_{iot-1} = \sum_{j=1}^{n} z_{ijt-1}\lambda_{jt-1} + s_{ilt-1}^- \quad i=1,…,r \quad t=1,…,T$$

$$y_{idot} = \sum_{j=1}^{n} y_{idjt}\lambda_{jt} - s_{idt}^+ \quad i=1,…,s \quad t=1,…,T$$

$$y_{iuot} = \sum_{j=1}^{n} y_{iujt}\lambda_{jt} + s_{iut}^- \quad i=1,…,p \quad t=1,…,T$$

$$z_{iot} = \sum_{j=1}^{n} z_{ijt}\lambda_{jt} - s_{ilt}^+ \quad i=1,…,r \quad t=1,…,T$$

$$\sum_{j=1}^{n} z_{ijt-1}\lambda_{jt-1} = \sum_{j=1}^{n} z_{ijt}\lambda_{jt} \quad \forall i, t=1,…,T$$

$$\lambda_{jt} \geq 0 \quad s_{it}^- \geq 0 \quad s_{idt}^+ \geq 0 \quad s_{iut}^- \geq 0 \quad s_{ilt}^- \geq 0 \quad s_{ilt}^+ \geq 0 \quad (1)$$

where x_{ijt} indicates input factors for DMUj at period t, while y_{idot} and y_{iuot} indicate desirable output and undesirable output (carbon emission) in period t, and z_{ijt} denotes the dynamic factors; s_{it}^-, s_{ilt-1}^-, s_{ilt}^+ are all slack variables, indicating excesses in input resources, dynamic excesses in input resource and dynamic shortfalls in output, respectively. s_{idt}^+ and s_{iut}^- indicate desirable output shortfalls and undesirable output excesses, respectively.

It is not hard to see that $\rho \in [0,1]$, and it will monotonously decrease along with the increase of input and output slack variables. If and only if $s_{it}^- = s_{idt}^+ = s_{iut}^- = s_{ilt-1}^- = 0$, $\rho = 1$, and it is called overall efficient. The smaller the ρ is, the less efficient the object will be. This paper defines the ρ^* as the dynamic efficiency with carbon emission constraint under changeable return to scale for the thermal power industry in China.

3.2. Data

Data are obtained from "China Statistical Yearbook" "China Energy Statistical Yearbook", "China Industry statistical Yearbook", "China Labour Statistical Yearbook", "China Electrical Statistical Yearbook" and "China Economic Census Yearbook". All of these yearbooks cover power generation, capital, labor force and energy

input of the power industry for 31 provinces in China. However, because there are no statistics data for labor for power generation companies in Tibet, and given that its power generation is far below other provinces, Tibet was removed from our sample.

Carbon emission factors are included in the model when we estimate the dynamic efficiency. At present, the input factors which have been wildly used in production functions include labor force, capital and energy consumption (He [4]). Desirable outputs include GDP and value of industrial output, and the undesirable outputs include pollution factor and carbon emissions. The method adopted by Lei [5] used efficiency of energy input as input factors instead of energy consumption. This provides valuable lessons for total factor productivity.

Following some previous studies and considering the reality of the power sector, energy input (indicated by energy input per unit generation) and industrial labor forces are taken as the input factors. Power generation is selected as the desirable output and carbon emission (indicated by carbon emission per unit generation) as the undesirable output in accordance with the energy input factor.

At the same time, capital stock is chosen as the dynamic factors to measure sustainable development; because the investment of capital stock has hysteresis in input and continuity in outcome. This feature of capital stock is in accordance with the inter-period characteristics of dynamic factors. Following Tone and Tsutsui [28], capital stock of the previous year as input factor and the capital stock of the current year are taken as the output factor, to analyze the across-period effect of dynamic factors. The final efficiency results would be Energy-Efficiency-Dynamic Total Factor Productivity (ECDTFP). The explanations are as follows.

1. *Desirable outputs (power generation)*: Power generation which is the most important indicator of the power sector, can reflect the operational efficiency of the power sector (Qu Qianqian et al. [26]). This paper choose provincial thermal power generation as the desirable output. The data are from "China Energy Statistical Yearbook".

2. *Undesirable outputs (carbon emission per unit quantity of electricity)*: choosing this indicator means the paper would analyze how the efficiency of carbon emission in power industry would affect the ECDTFP. The indicator is calculated by Eq. (2)

$$C_{ie,t} = \frac{C_{itot,t}}{G_{it}} = \frac{\sum_{j=1}^{n} Q_j \zeta_j}{G_{it}} \tag{2}$$

In Eq. (2) $C_{ie,t}$ is the indicator this paper defined. G_{it} denotes the power generated. $C_{itot,t}$ is the total carbon emission, which is calculated through $\sum_{j=1}^{n} Q_j \zeta_j$. Q denotes the quantity of energy consumption, ζ indicates the emission index of different fossil fuel, j denotes fossil fuel type. Statistics for Q_j are adopted from provincial physical energy balance sheet of China energy statistical yearbook. Energy consumption data are converted into standard coal.

3. *E_{it} Energy input (energy input per unit quantity of electricity)*: To examine how energy input efficiency would affect the ECDTFP in the power industry directly, the paper chooses the energy input

per unit quantity of electricity as the input indicator. Coal, natural gas and oil consumption data are from "China Energy Statistical Yearbook" which then are adjusted to tons of standard coal, and are divided by quantity of provincial power generation as Eq. (3).

$$E_{it} = Q_{it}/G_{it} \tag{3}$$

where Q_{it} and G_{it} denote the energy consumption and power generation quantities in province i at time t.

4. *L_{it} (Labor input)*: In order to estimate the efficiency of thermal power industry, the working time of employed persons should be taken as the labor resource input. However, official statistics on labor force of thermal power sector is unavailable, so this paper adopts employment data of Electricity, Heat Production and Supply Industry from "China Labor Statistical Yearbook". The employment data in the yearbook contains two scopes: the average annual value and the value at the end of the year. The

Table 2
Provincial ECDTFP of electricity industry in China.

	2005	2006	2007	2008	2009	2010	Average of 5 years
Anhui	0.55	1.00	0.66	1.00	0.61	0.50	0.72
Beijing	1.00	0.41	0.37	1.00	0.37	1.00	0.69
Fujian	0.64	0.65	0.64	0.59	0.63	0.59	0.62
Gansu	0.43	0.47	0.56	0.55	1.00	0.51	0.59
Guangdong	1.00	1.00	1.00	0.78	1.00	1.00	0.96
Guangxi	0.45	0.44	1.00	0.60	0.64	0.53	0.61
Guizhou	0.58	1.00	0.63	0.74	1.00	0.62	0.76
Hainan	0.31	0.32	0.33	0.28	0.39	0.31	0.32
Hebei	0.57	0.63	0.59	0.51	0.72	0.51	0.59
Henan	0.53	0.55	0.61	0.62	0.73	0.54	0.60
Heilongjiang	0.34	0.33	0.43	0.34	0.50	0.35	0.38
Hubei	1.00	0.80	1.00	1.00	1.00	1.00	0.97
Hunan	0.50	1.00	0.52	0.50	0.58	0.53	0.61
Jilin	0.36	0.38	0.34	0.42	0.40	1.00	0.48
Jiangsu	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Jiangxi	0.32	0.36	0.39	0.39	0.36	0.38	0.37
Liaoning	0.46	0.43	0.46	0.42	0.53	0.49	0.46
Inner Mongolia	1.00	0.59	1.00	1.00	0.69	0.68	0.83
Ningxia	1.00	1.00	1.00	0.49	0.47	0.47	0.74
Qinghai	0.59	0.61	0.57	0.53	1.00	1.00	0.72
Shandong	0.74	1.00	1.00	1.00	1.00	1.00	0.96
Shanxi	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Shaanxi	0.40	0.40	0.45	0.49	1.00	0.41	0.53
Shanghai	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Sichuan	0.60	0.65	0.68	0.68	1.00	1.00	0.77
Tianjin	0.49	0.46	0.48	0.45	0.51	0.50	0.48
Xinjiang	0.34	0.35	0.39	0.46	0.46	1.00	0.50
Yunnan	0.50	0.84	0.56	0.71	1.00	0.84	0.74
Zhejiang	1.00	1.00	0.78	0.71	1.00	0.83	0.89
Chongqing	0.37	0.38	0.41	0.41	0.42	0.40	0.40
Average for each region							
Total average	0.64	0.67	0.66	0.66	0.73	0.70	0.68
Northern China	0.80	0.68	0.74	0.83	0.72	0.78	0.76
North-east of China	0.39	0.38	0.41	0.40	0.48	0.61	0.44
Eastern China	0.84	0.93	0.82	0.86	0.85	0.79	0.85
Central China	0.55	0.63	0.60	0.60	0.68	0.64	0.62
Northwest	0.55	0.57	0.59	0.51	0.79	0.68	0.61
Southern	0.57	0.72	0.70	0.62	0.81	0.66	0.68

Table 1
Variable descriptions.

|	Variables		Mean	Minimum	Maximum	Coefficient of variation
Input factors	Energy input	kg/MWh	28.6	8.0	44.5	0.28
	Labor input	Thousand people	78.046	10.628	175.222	0.52
Dynamic factors	Capital stock (last year)	Billion yuan (2000)	94.926	9.817	375.959	0.70
	Capital stock (this year)	Billion yuan (2000)	106.567	10.115	423.041	0.68
Output factors	Power generation	TWh	1114.17	82.00	3359.00	0.69
	Carbon emissions	kg/MWh	74.0	20.3	116.1	0.28
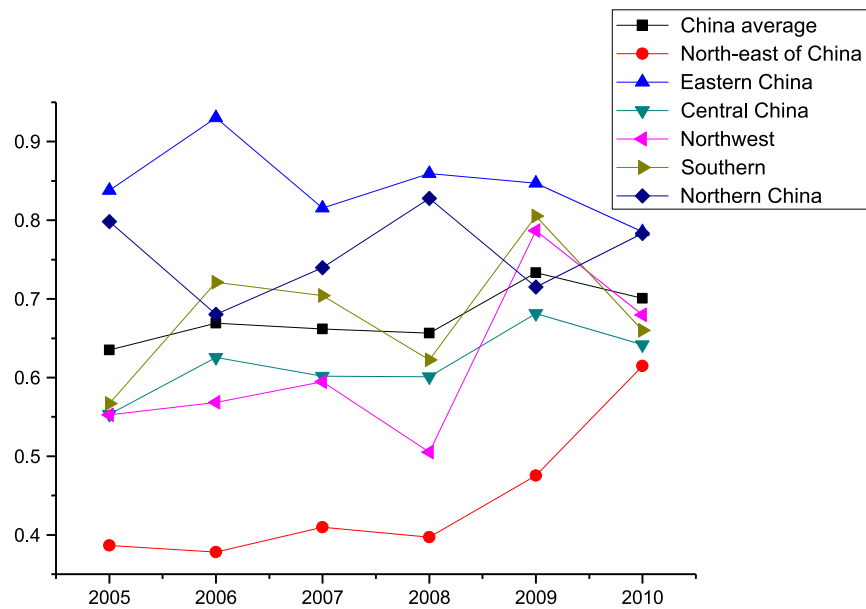
Fig. 4. Trends of regional ECDTFP in China's power industry. *Notes*: Data in Fig. 4 are the processed data (regional average values) based on the results of D-SBM model.

figures are adjusted into average annual value by calculating the average value of the adjacent two years.

5. *Dynamic factors (capital stock)*: The capital stock of the power industry in 2005–2010 is calculated using perpetual inventory method as in Eq. (4).

$$K_{it} = K_{it-1} + I_{it} - \delta_{it} K_{it-1} \qquad (4)$$

This paper adopts the method of He [4], and adjusts the figures into 2000 price. Data are from "China Industry Statistical Yearbook".

Variable descriptions are listed in Table 1.

4. Results and analysis

Eq. (1) is a nonlinear programming (NLP) problem having an objective function and constraints which can be converted to linear programming through the Charnes–Cooper method. The evaluation results obtained by Matlab[2] are listed in Table 2.

The results show that the provincial ECDTFP of the power industry in China maintain between 0.6 and 0.7, with a certain upward trend. The ECDTFP in provinces like Shang Hai, Jiang Su, Shan Xi, Guang Dong, Hu Bei are around the productivity frontier (see Table 2, Fig. 4). This can be also confirmed by some statistics, which directly corresponding with our results. In 2010, provinces with auxiliary power ratio lower than 6% includes Shang Hai (4.98%), Jiang Su (5.27%), Zhe Jiang (5.34%), and Guang Dong (5.97%). Provinces with lower ECDTFP, such as Ji Lin (7.82%), Hei Longjiang (7.13%), Liao Ning (6.99%), Hai Nan (7.57%), Yun Nan (6.93%) and Shaan Xi (7.23%), turned out to be those with higher auxiliary power ratio.

Fig. 4 reflects the variation trend of the regional ECDTFP of China's power industry under carbon emission constraint over 2005–2010.

Relatively speaking, ECDTFP of northern and eastern China are higher than that in the other regions of China. The time-varying trend of efficiency in northern and eastern China is not significant for that the efficiency in these regions is high enough. Energy efficiency of regions (such as northeastern and northwestern China) with power industry that has relatively lower average

efficiency has the upward trend. In summary, the efficiencies of China's power industry are not satisfying as the carbon emission and sustainable development requirements have not gotten as much attention as they deserve.

From the year 2005 to 2010, the differences in ECDTFP among the provinces in China are steadily narrowing. It should be noted that the ECDTFP value of individual regions decreased due to the extension of productivity frontier promoted by technical advancement over time (see Fig. 5). In this situation, distances between frontier and efficiency in backward regions were getting larger, which exhibits as a relatively lower value of ECDTFP. The regional overall ECDTFP values were improved over time, with some fluctuation caused by external factors like weather in the particular regions.

5. Investment structure reform in China's power industry: models and empirical researches

To further investigate the impacting factors of the efficiency in China's power industry, this section will apply the two-stage method of DEA proposed by Fried et al. [35]. The dependent variable in the model is a censored one, because of the efficiency value based on DEA are between 0 and 1. Thus, we will adopt a Censored Regression Model – Tobit model. The basic model is as in Eq. (5):

$$eff_{it} = \alpha_0 + \alpha_1 reform_{it} + \alpha_2 Z_{it} + \varepsilon_{it} \qquad (5)$$

In Eq. (5) $reform_{it}$ denotes the investment structure reform variable, Z_{it} denotes the regional variation of control variables in China's power industry, ε_{it} denotes random perturbed variable. eff_{it} is the efficiency of China's power industry indicated by ECDTPF which has been calculated above.

$reform_{it}$ is the key variable in this paper. In the process of reform in the power industry, there exists private and foreign capital inflow. This paper focuses on investment reform which specifically means breaking state monopoly and attracting foreign and private capital.

The properties of the investment structure in China's power industry are demonstrated in Fig. 6. According to the basic statistics of different enterprises, it can be found that: in the power sector, foreign enterprises usually have advanced operational experience and

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[2] The program code of D-SBM are based on the code given by Peng and Xu [32] and Quan [33], Zhu and Du [34].The software version is Matlab 2012b.
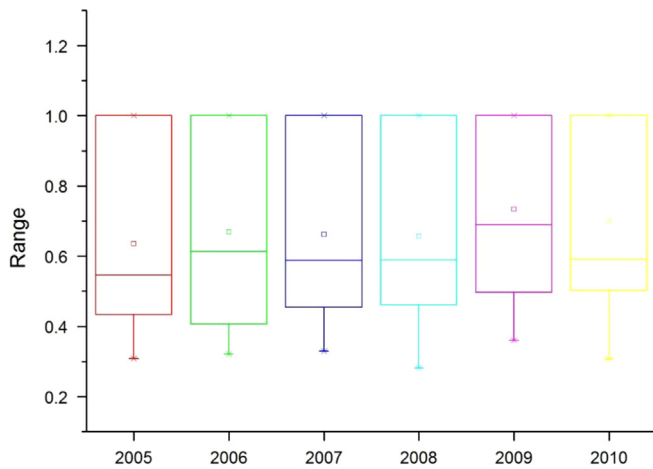
Fig. 5. Statistic properties of ECDTFP in China's power industry from 2005 to 2010. *Note*: The box-chart give the median, first quartile ($x0.25$) and third quartile ($x0.75$) of the data by using the lines in a box in Fig. 5. The interquartile rage (IQR) is calculated by subtracting the first quartile from the third quartile ($x0.75 - x0.25$). The smallest, largest and the average values line inside the figure with symbols. There is no outlier in this data which is defined as more than $1.5 \times$ IQR lower than the first quartile or $1.5 \times$ IQR higher than the third quartile.

high outputs. This might be the key variable that will affect the result of reform. To improve the efficiency of the power sector, the foreign investment would be more significant in a short run because it requires high level of market environment and standardized government management. When foreign investment proportion increases in the power industry, the direct participation of government in economic activities would be reduced. The reduction will lead to optimization of market environment and standardization.

The present literatures about market-oriented reform and structure reform in industries often focus on the percentage of state-owned companies in an industry, and the representative indicator would be the percentage of state-owned enterprise staff in an industry. However, there are two problems with an indicator like this: first, in some ways, employees can reflect the composition of capital investment in an industry and; second, this indicator only focuses on the impact from one specific aspect like state-owned companies or foreign companies respectively. However, the investigation of the impact of both breaking state monopoly and bringing in foreign investments at the same time is necessary. This means these indicators cannot meet the requirements. Therefore, a new indicator is constructed which can reflect both impacts. This paper chooses the ratio of foreign capital and state-capital in power industry as the indicator of investment structure reform. So *reform=foreign capital/state capital*.
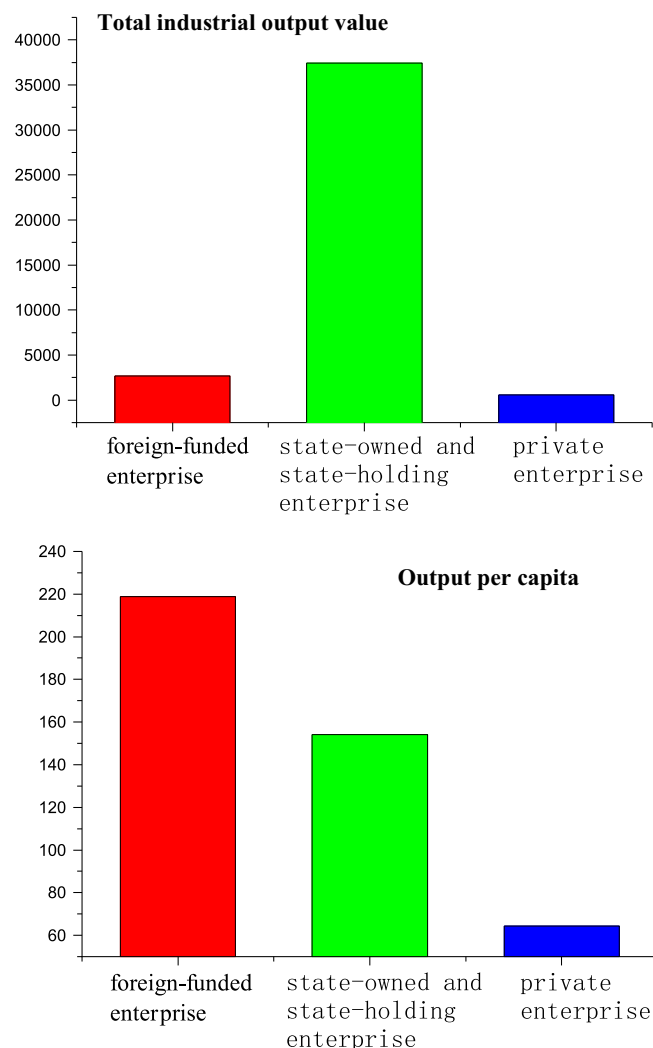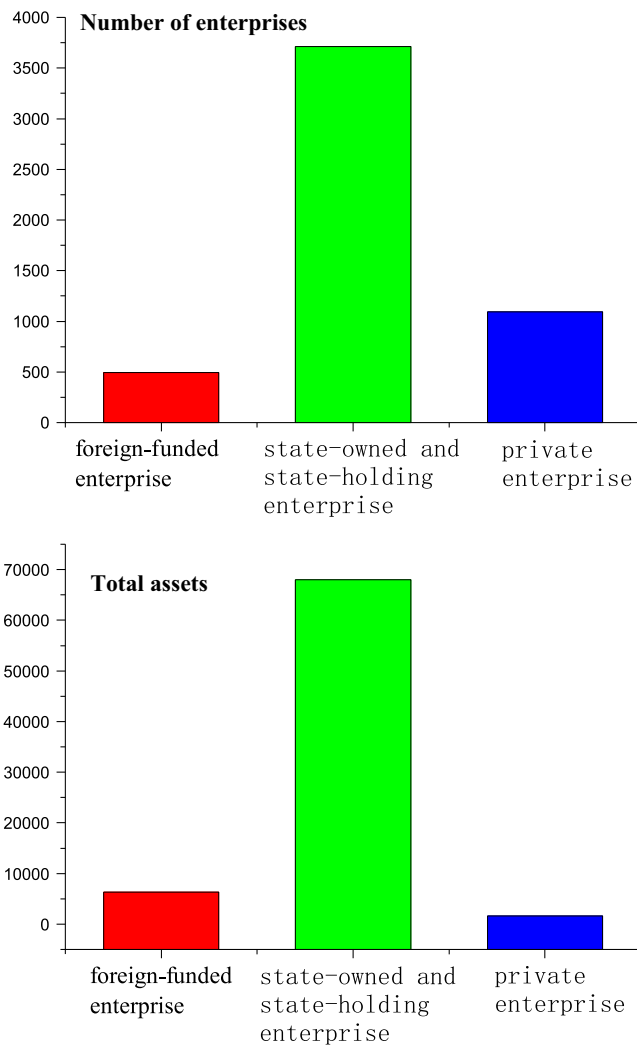

Fig. 6. Investment structure of China's power industry. *Data source*: China Statistical Yearbook 2011.

It can be seen from Fig. 7 that the diversity of reform indicator among provinces decreased over time, and there still exist zeros in some regions.

Besides, the ECDTFP would be influenced by industry concentration, electric power structure, electricity price and technology at varying degree. So some correlative variables are introduced to eliminate the influence caused by other indicators. The detailed explanations are as follows (see Table 3).

1. Industry concentration: He [4] used the scale of single enterprise in an industry to indicate the industry concentration. It is accepted that the larger the average scale of single enterprise is, the higher the industry concentration is. Industry concentration=total assets/number of enterprises. Data are obtained from "China Industry statistical Yearbook".
2. Electricity price: Represented by the electricity prices for industrial use in 30 typical cities. Data are from CEIC database.
3. Electricity structure: Indicated by the share of thermal power generation in power sector. In the power industry, there are large differences in efficiency among different modes of electricity generation. Thermal power generation accounts for a very high share of total generation in China. This indicator can show the main structure of every province, so as to investigate the impact of electricity structure.
4. Technology: Provincial technology investment intensity. It is accepted in economic theories that improvement in technology
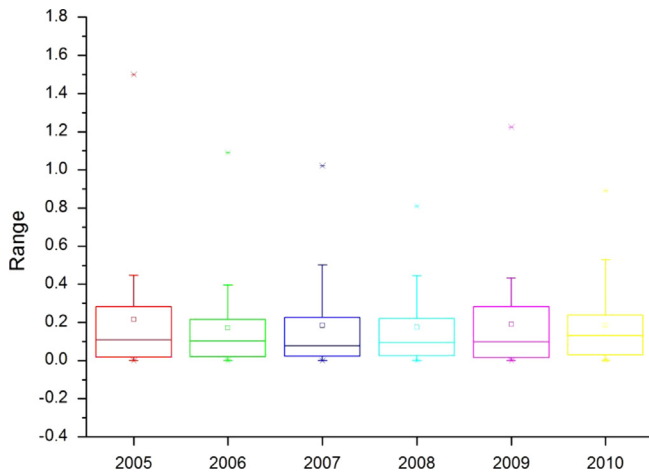
would promote the efficiency of an industry. Wu and Fu [30] adopted the relative wage level among sectors to measure the industrial technology investment intensity. In this paper, a similar proxy is adopted to calculate an indicator judging the interregional technology investment intensity (Eq. (6)).

$$TECH_{kt} = Wage_{kt} / \frac{\sum_{k=1}^{N} Wage_{kt}}{N} \tag{6}$$

in which, $Wage_{kt}$ indicates the wage level of k province in time t and N indicates 30 provinces. Data are from CEIC database.

5. Urbanization levels: The philosophy of economic development, environmental protection and energy consumption in an area are closely related to the degree of urbanization. The process of urbanization means production gathering and market enlargement which would be beneficial to improve productivity. However, massive consumption of electricity accompanies urbanization, which means there may be risks of not satisfying the requirement of sustainable development. So the impacts of urbanization need more investigation. The proportion of non-rural population would be the proxy variable in this paper (cf. Jiang and Lin [36]; Lin and Ouyang [37]). Data are from 'China Population Statistics Yearbook' and 'China Population and Employment Statistics Yearbook'.

The results of Tobit model are shown in Table 4. In model 1, only the reform variable is taken into consideration to investigate the relationship between reform and efficiency. The results illustrate that the reform variable positively correlates with regional efficiency of power industry. That means reducing the proportion of state capital and bringing in foreign capital at the same time will improve the efficiency level of the power industry. This conclusion is consistent with our preliminary estimation. Fig. 8 presents this relationship directly. The similar conclusions that reducing the proportion of state capital will promote environmental efficiency were drawn by Zhu [31] and Tu and Liu [38].

Based on model 1, industry concentration is brought in as the control variable in model 2. The coefficient of reform is also significant at 1% level, while the coefficient of industry concentration is significant at 5% level. The different levels show the positive effect of industry concentration on efficiency. From another point of view, this result shows the natural monopoly in the power industry to some extent.

Based on model 2, electricity structure is introduced as the control variable in model 3. The result suggests that all the coefficients are statistically significant in the model. It is also

Fig. 7. Statistic characteristics of reform indicator. *Note*: The box-chart gives the median, 1st quartile ($x0.25$) and 3rd quartile ($x0.75$) of the data by using the lines in a box in Fig. 7. The interquartile rage (IQR) is calculated by subtracting the 1st quartile from the 3rd quartile ($x0.75 - x0.25$). The smallest, largest and the average values line inside the figure with symbols. Outlier here is defined as more than $1.5 \times$ IQR lower than the 1st quartile or $1.5 \times$ IQR higher than the 3rd quartile. In this figure, there is an outlier which is $1.5 \times$ IQR higher than the 3rd quartile. The largest value and the smallest value that is not an outlier is connected to the box via a horizontal line.

Table 3
Variable description.

Variables	Symbols	Definition
Efficiency	ECDTPF	Gained from D-SBM model
Investment reform	Reform	Foreign capital/state capital
Industry concentration	Concentr	Total assets/numbers of companies × 100%
Electricity structure	Stru	Proportion of thermal power generation
Technology	Tech	interregional relative wages level
Urbanization	Urban	Non-rural population/population × 100%
Electricity price	Price	Electricity prices for industrial use in 30 typical cities.

Table 4
Regression results of Tobit model.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Reform	0.381	0.398	0.423	0.457	0.419	0.424
	3.29***	3.76***	3.82***	4.24***	3.79***	3.81***
Concentr		0.0076	0.0082	0.0074	0.0068	0.0060
		2.26**	2.44**	2.19**	1.96**	1.41
Stru			−0.215	−0.271	−0.302	−0.336
			−1.80*	−2.19**	−2.39**	−2.20**
Tech				0.419	0.454	0.507
				1.45*	1.59*	1.66*
Price					0.304	0.292
					0.99	0.97
Urban						0.001
						0.48
_cons	0.676	0.580	0.737	0.357	0.193	0.139
	17.79***	13.35***	7.70***	1.30	0.66	0.44

*** Coefficient is significant at 1% level.
** Coefficient is significant at 5% level.
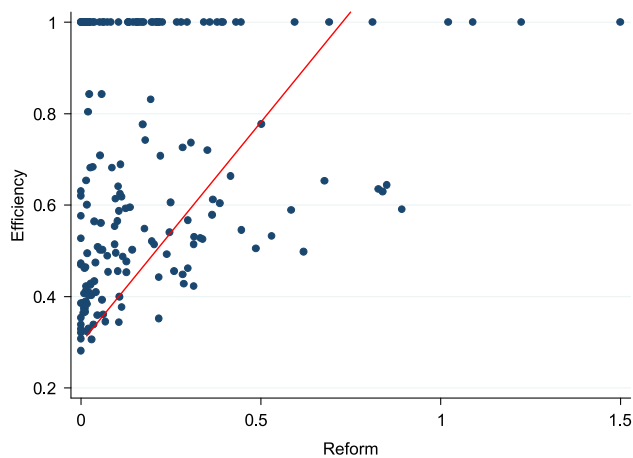* Coefficient is significant at 10% level.

Fig. 8. Scatter plot of *reform* and *efficiency*.

found that the electricity structure has significant negative effect on efficiency in the power industry which means that promotion of thermal power generation will lead to the reduction of efficiency in the whole electricity industry.

In models 4–6, this paper brings in regional technology investment intensity, electricity price and urbanization as the control variables step by step. Results demonstrate the significance of reform, which means we can basically confirm the positive effect of investment structure reform. At the same time, industrial concentration, electricity structure and technology also affect the efficiency. In recent years, policies such as 'developing large units and suppressing small ones' have been proposed to increase efficiency in the power industry. During the 11th 5-year plan period, China has closed small thermal power factories of about 70 million kilowatts in total, and our paper demonstrates the reasonableness of this measure from the empirical point.

6. Conclusion and policy suggestion

This paper uses the D-SBM model to measure efficiency in China's power industry during the year 2005–2010. Given the high proportion of state capital in China's power industry, an empirical research is promoted on the effect of investment structure reform on improving efficiency in the industry. The direct conclusion and policy suggestions are as follows.

First, there exists a relatively vast room for promotion of the efficiency of the power industry. In 2005–2010, the average value of ECDTFP is measured between 0.6 and 0.8, which indicates a great potential that can be tapped in the future. Besides, ECDTFP of the power industry differs from one region to another. Narrowing this gap will become an important way to realize the energy conservation and carbon mitigation in the power industry.

Second, the investment structure reform of the power industry will provide significant impetus to improve efficiency. As the result shows, the more deeply the reform was carried out, the higher the efficiency will be, and vice-versa. In order to promote the system reform in the power industry, the foreign capital should be positively introduced while lowering proportion of state-owned assets and breaking state monopoly. The advanced production experience, management expertise and technology of foreign investors will effectively promote the scientific development of China's power industry. However, the state monopolistic nature of the power industry creates conditions for government to control the tariff. Without market-oriented mechanism, government-controlled tariff obstructs the foreign capital inflow into the industry. Above all, the government should firstly focus on

formulating policies and measures to establish a comparatively transparent and market-oriented investment environment in order to attract foreign investment funds (Lin and Yang [39]). It will be a significant way to achieve the ultimate goals of e efficiency improvement and low-carbon transition in the power industry.

Third, in terms of other factors affecting efficiency of China's power industry, the comparative high proportion of thermal power seems adverse to raising the ECDTFP. With the investment structure reform obtaining more remarkable result, the policy of "developing large units and suppressing small ones " exerts relatively significant impact on raising efficiency in the power industry, as testified by the result of this practical research. According to the inner requirement of low-carbon transition and sustainable development, the positive introduction of cleaner energy is the major trend in the future development of the power industry. Both gas power and renewable energy generation are the new production patterns on which the industry will focus. A positive correlation between technology investment intensity and efficiency is detected as well. Comparatively, some factors like tariff and urbanization rate are insignificant because of the special regulation on the power industry.

On the basis of the above analysis, the following means suggestion should be taken into consideration in order to promote the efficiency of China's power industry: 1. There is a need to support the development of clean energy. Specific power production structure targets that encourage clean energy taking the place of thermal power can be set. This can be encouraged through t policy, investment, technology and subsidies. 2. In order to achieve the scale effect in the power industry, the government should not only encourage the high technology enterprises to properly enlarge the production scale but could also close and consolidate some small and low-efficient plants under reasonable regulation. 3. With continuously enhanced regional technology investment, advanced production technology and management experience can actively promote efficiency of the power industry. 4. It is necessary to reform the tariff pricing mechanism and to establish the market-oriented pricing mechanism.

Furthermore, the estimation result verifies the positive effect of investment structure reform on power industry. By far, if the government makes no change to the present condition in terms of an active and step-by-step reform based on the structure and system, the result of the system reform will be unsatisfactory. Foreign capital is synonymous with advanced production technology and management experience. With the introduction of foreign capital, the government can seize the opportunity to actively support domestic industry and strengthen its competitiveness by improving production efficiency and management technology to thoroughly complete the market-oriented reform in the power industry.

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